When societies do adopt a new technology from the society that invented it, the diffusion may occur in many different contexts. They include peaceful trade (as in the spread of transistors from the United States to Japan in 1954), espionage (the smuggling of silkworms from Southeast Asia to the Mideast in A.D. 552), emigration (the spread of French glass and clothing manufacturing techniques over Europe by the 200,000 Huguenots expelled from France in 1685), and war. A crucial case of the last was the transfer of Chinese papermaking techniques to Islam, made possible when an Arab army defeated a Chinese army at the battle of Talas River in Central Asia in A.D. 751, found some papermakers among the prisoners of war, and brought them to Samarkand to set up paper manufacture.

In Chapter 12 we saw that cultural diffusion can involve either detailed "blueprints" or just vague ideas stimulating a reinvention of details. While Chapter 12 illustrated those alternatives for the spread of writing, they also apply to the diffusion of technology. The preceding paragraph gave examples of blueprint copying, whereas the transfer of Chinese porcelain technology to Europe provides an instance of long-drawn-out idea diffusion. Porcelain, a fine-grained translucent pottery, was invented in China around the 7th century A.D. When it began to reach Europe by the Silk Road in the 14th century (with no information about how it was manufactured), it was much admired, and many unsuccessful attempts were made to imitate it. Not until 1707 did the German alchemist Johann Böttger, after lengthy experiments with processes and with mixing various minerals and clays together, hit upon the solution and establish the now famous Meissen porcelain works. More or less independent later experiments in France and England led to Sèvres, Wedgwood, and Spode porcelains. Thus, European potters had to reinvent Chinese manufacturing methods for themselves, but they were stimulated to do so by having models of the desired product before them.

Depending on their geographic location, societies differ in how readily they can receive technology by diffusion from other societies. The most isolated people on Earth in recent history were the Aboriginal Tasmanians, living without oceangoing watercraft on an island 100 miles from Australia, itself the most isolated continent. The Tasmanians had no contact with other societies for 10,000 years and acquired no new technology

other than what they invented themselves. Australians and New Guineans, separated from the Asian mainland by the Indonesian island chain, received only a trickle of inventions from Asia. The societies most accessible to receiving inventions by diffusion were those embedded in the major continents. In these societies technology developed most rapidly, because they accumulated not only their own inventions but also those of other societies. For example, medieval Islam, centrally located in Eurasia, acquired inventions from India and China and inherited ancient Greek learning.

The importance of diffusion, and of geographic location in making it possible, is strikingly illustrated by some otherwise incomprehensible cases of societies that abandoned powerful technologies. We tend to assume that useful technologies, once acquired, inevitably persist until superseded by better ones. In reality, technologies must be not only acquired but also maintained, and that too depends on many unpredictable factors. Any society goes through social movements or fads, in which economically useless things become valued or useful things devalued temporarily. Nowadays, when almost all societies on Earth are connected to each other, we cannot imagine a fad's going so far that an important technology would actually be discarded. A society that temporarily turned against a powerful technology would continue to see it being used by neighboring societies and would have the opportunity to reacquire it by diffusion (or would be conquered by neighbors if it failed to do so). But such fads can persist in isolated societies.

A famous example involves Japan's abandonment of guns. Firearms reached Japan in A.D. 1543, when two Portuguese adventurers armed with harquebuses (primitive guns) arrived on a Chinese cargo ship. The Japanese were so impressed by the new weapon that they commenced indigenous gun production, greatly improved gun technology, and by A.D. 1600 owned more and better guns than any other country in the world.

But there were also factors working against the acceptance of firearms in Japan. The country had a numerous warrior class, the samurai, for whom swords rated as class symbols and works of art (and as means for subjugating the lower classes). Japanese warfare had previously involved single combats between samurai swordsmen, who stood in the open, made ritual speeches, and then took pride in fighting gracefully. Such behavior became lethal in the presence of peasant soldiers ungracefully blasting away with guns. In addition, guns were a foreign invention and grew to

be despised, as did other things foreign in Japan after 1600. The samurai-controlled government began by restricting gun production to a few cities, then introduced a requirement of a government license for producing a gun, then issued licenses only for guns produced for the government, and finally reduced government orders for guns, until Japan was almost without functional guns again.

Contemporary European rulers also included some who despised guns and tried to restrict their availability. But such measures never got far in Europe, where any country that temporarily swore off firearms would be promptly overrun by gun-toting neighboring countries. Only because Japan was a populous, isolated island could it get away with its rejection of the powerful new military technology. Its safety in isolation came to an end in 1853, when the visit of Commodore Perry's U.S. fleet bristling with cannons convinced Japan of its need to resume gun manufacture.

That rejection and China's abandonment of oceangoing ships (as well as of mechanical clocks and water-driven spinning machines) are well-known historical instances of technological reversals in isolated or semi-isolated societies. Other such reversals occurred in prehistoric times. The extreme case is that of Aboriginal Tasmanians, who abandoned even bone tools and fishing to become the society with the simplest technology in the modern world (Chapter 15). Aboriginal Australians may have adopted and then abandoned bows and arrows. Torres Islanders abandoned canoes, while Gaua Islanders abandoned and then readopted them. Pottery was abandoned throughout Polynesia. Most Polynesians and many Melanesians abandoned the use of bows and arrows in war. Polar Eskimos lost the bow and arrow and the kayak, while Dorset Eskimos lost the bow and arrow, bow drill, and dogs.

These examples, at first so bizarre to us, illustrate well the roles of geography and of diffusion in the history of technology. Without diffusion, fewer technologies are acquired, and more existing technologies are lost.

BECAUSE TECHNOLOGY BEGETS more technology, the importance of an invention's diffusion potentially exceeds the importance of the original invention. Technology's history exemplifies what is termed an autocatalytic process: that is, one that speeds up at a rate that increases with time, because the process catalyzes itself. The explosion of technology since the Industrial Revolution impresses us today, but the medieval explosion was

equally impressive compared with that of the Bronze Age, which in turn dwarfed that of the Upper Paleolithic.

One reason why technology tends to catalyze itself is that advances depend upon previous mastery of simpler problems. For example, Stone Age farmers did not proceed directly to extracting and working iron, which requires high-temperature furnaces. Instead, iron ore metallurgy grew out of thousands of years of human experience with natural outcrops of pure metals soft enough to be hammered into shape without heat (copper and gold). It also grew out of thousands of years of development of simple furnaces to make pottery, and then to extract copper ores and work copper alloys (bronzes) that do not require as high temperatures as does iron. In both the Fertile Crescent and China, iron objects became common only after about 2,000 years of experience of bronze metallurgy. New World societies had just begun making bronze artifacts and had not yet started making iron ones at the time when the arrival of Europeans truncated the New World's independent trajectory.

The other main reason for autocatalysis is that new technologies and materials make it possible to generate still other new technologies by recombination. For instance, why did printing spread explosively in medieval Europe after Gutenberg printed his Bible in A.D. 1455, but not after that unknown printer printed the Phaistos disk in 1700 B.C.? The explanation is partly that medieval European printers were able to combine six technological advances, most of which were unavailable to the maker of the Phaistos disk. Of those advances—in paper, movable type, metallurgy, presses, inks, and scripts—paper and the idea of movable type reached Europe from China. Gutenberg's development of typecasting from metal dies, to overcome the potentially fatal problem of nonuniform type size, depended on many metallurgical developments: steel for letter punches, brass or bronze alloys (later replaced by steel) for dies, lead for molds, and a tin-zinc-lead alloy for type. Gutenberg's press was derived from screw presses in use for making wine and olive oil, while his ink was an oil-based improvement on existing inks. The alphabetic scripts that medieval Europe inherited from three millennia of alphabet development lent themselves to printing with movable type, because only a few dozen letter forms had to be cast, as opposed to the thousands of signs required for Chinese writing.

In all six respects, the maker of the Phaistos disk had access to much less powerful technologies to combine into a printing system than did Gutenberg. The disk's writing medium was clay, which is much bulkier

and heavier than paper. The metallurgical skills, inks, and presses of 1700 B.C. Crete were more primitive than those of A.D. 1455 Germany, so the disk had to be punched by hand rather than by cast movable type locked into a metal frame, inked, and pressed. The disk's script was a syllabary with more signs, of more complex form, than the Roman alphabet used by Gutenberg. As a result, the Phaistos disk's printing technology was much clumsier, and offered fewer advantages over writing by hand, than Gutenberg's printing press. In addition to all those technological drawbacks, the Phaistos disk was printed at a time when knowledge of writing was confined to a few palace or temple scribes. Hence there was little demand for the disk maker's beautiful product, and little incentive to invest in making the dozens of hand punches required. In contrast, the potential mass market for printing in medieval Europe induced numerous investors to lend money to Gutenberg.

HUMAN TECHNOLOGY DEVELOPED from the first stone tools, in use by two and a half million years ago, to the 1996 laser printer that replaced my already outdated 1992 laser printer and that was used to print this book's manuscript. The rate of development was undetectably slow at the beginning, when hundreds of thousands of years passed with no discernible change in our stone tools and with no surviving evidence for artifacts made of other materials. Today, technology advances so rapidly that it is reported in the daily newspaper.

In this long history of accelerating development, one can single out two especially significant jumps. The first, occurring between 100,000 and 50,000 years ago, probably was made possible by genetic changes in our bodies: namely, by evolution of the modern anatomy permitting modern speech or modern brain function, or both. That jump led to bone tools, single-purpose stone tools, and compound tools. The second jump resulted from our adoption of a sedentary lifestyle, which happened at different times in different parts of the world, as early as 13,000 years ago in some areas and not even today in others. For the most part, that adoption was linked to our adoption of food production, which required us to remain close to our crops, orchards, and stored food surpluses.

Sedentary living was decisive for the history of technology, because it enabled people to accumulate nonportable possessions. Nomadic hunter-

gatherers are limited to technology that can be carried. If you move often and lack vehicles or draft animals, you confine your possessions to babies, weapons, and a bare minimum of other absolute necessities small enough to carry. You can't be burdened with pottery and printing presses as you shift camp. That practical difficulty probably explains the tantalizingly early appearance of some technologies, followed by a long delay in their further development. For example, the earliest attested precursors of ceramics are fired clay figurines made in the area of modern Czechoslovakia 27,000 years ago, long before the oldest known fired clay vessels (from Japan 14,000 years ago). The same area of Czechoslovakia at the same time has yielded the earliest evidence for weaving, otherwise not attested until the oldest known basket appears around 13,000 years ago and the oldest known woven cloth around 9,000 years ago. Despite these very early first steps, neither pottery nor weaving took off until people became sedentary and thereby escaped the problem of transporting pots and looms.

Besides permitting sedentary living and hence the accumulation of possessions, food production was decisive in the history of technology for another reason. It became possible, for the first time in human evolution, to develop economically specialized societies consisting of non-food-producing specialists fed by food-producing peasants. But we already saw, in Part 2 of this book, that food production arose at different times in different continents. In addition, as we've seen in this chapter, local technology depends, for both its origin and its maintenance, not only on local invention but also on the diffusion of technology from elsewhere. That consideration tended to cause technology to develop most rapidly on continents with few geographic and ecological barriers to diffusion, either within that continent or on other continents. Finally, each society on a continent represents one more opportunity to invent and adopt a technology, because societies vary greatly in their innovativeness for many separate reasons. Hence, all other things being equal, technology develops fastest in large productive regions with large human populations, many potential inventors, and many competing societies.

Let us now summarize how variations in these three factors—time of onset of food production, barriers to diffusion, and human population size—led straightforwardly to the observed intercontinental differences in the development of technology. Eurasia (effectively including North

Africa) is the world's largest landmass, encompassing the largest number of competing societies. It was also the landmass with the two centers where food production began the earliest: the Fertile Crescent and China. Its east–west major axis permitted many inventions adopted in one part of Eurasia to spread relatively rapidly to societies at similar latitudes and climates elsewhere in Eurasia. Its breadth along its minor axis (north–south) contrasts with the Americas' narrowness at the Isthmus of Panama. It lacks the severe ecological barriers transecting the major axes of the Americas and Africa. Thus, geographic and ecological barriers to diffusion of technology were less severe in Eurasia than in other continents. Thanks to all these factors, Eurasia was the continent on which technology started its post-Pleistocene acceleration earliest and resulted in the greatest local accumulation of technologies.

North and South America are conventionally regarded as separate continents, but they have been connected for several million years, pose similar historical problems, and may be considered together for comparison with Eurasia. The Americas form the world's second-largest landmass, significantly smaller than Eurasia. However, they are fragmented by geography and by ecology: the Isthmus of Panama, only 40 miles wide, virtually transects the Americas geographically, as do the isthmus's Darien rain forests and the northern Mexican desert ecologically. The latter desert separated advanced human societies of Mesoamerica from those of North America, while the isthmus separated advanced societies of Mesoamerica from those of the Andes and Amazonia. In addition, the main axis of the Americas is north–south, forcing most diffusion to go against a gradient of latitude (and climate) rather than to operate within the same latitude. For example, wheels were invented in Mesoamerica, and llamas were domesticated in the central Andes by 3000 B.C., but 5,000 years later the Americas' sole beast of burden and sole wheels had still not encountered each other, even though the distance separating Mesoamerica's Maya societies from the northern border of the Inca Empire (1,200 miles) was far less than the 6,000 miles separating wheel- and horse-sharing France and China. Those factors seem to me to account for the Americas' technological lag behind Eurasia.

Sub-Saharan Africa is the world's third largest landmass, considerably smaller than the Americas. Throughout most of human history it was far more accessible to Eurasia than were the Americas, but the Saharan desert is still a major ecological barrier separating sub-Saharan Africa from

Eurasia plus North Africa. Africa's north–south axis posed a further obstacle to the diffusion of technology, both between Eurasia and sub-Saharan Africa and within the sub-Saharan region itself. As an illustration of the latter obstacle, pottery and iron metallurgy arose in or reached sub-Saharan Africa's Sahel zone (north of the equator) at least as early as they reached western Europe. However, pottery did not reach the southern tip of Africa until around A.D. 1, and metallurgy had not yet diffused overland to the southern tip by the time that it arrived there from Europe on ships.

Finally, Australia is the smallest continent. The very low rainfall and productivity of most of Australia makes it effectively even smaller as regards its capacity to support human populations. It is also the most isolated continent. In addition, food production never arose indigenously in Australia. Those factors combined to leave Australia the sole continent still without metal artifacts in modern times.

Table 13.1 translates these factors into numbers, by comparing the continents with respect to their areas and their modern human populations. The continents' populations 10,000 years ago, just before the rise of food production, are not known but surely stood in the same sequence, since many of the areas producing the most food today would also have been productive areas for hunter-gatherers 10,000 years ago. The differences in population are glaring: Eurasia's (including North Africa's) is nearly 6 times that of the Americas, nearly 8 times that of Africa's, and 230 times that of Australia's. Larger populations mean more inventors and more competing societies. Table 13.1 by itself goes a long way toward explaining the origins of guns and steel in Eurasia.

All these effects that continental differences in area, population, ease of

TABLE 13.1 **Human Populations of the Continents**

Continent	*1990 Population*	*Area (square miles)*
Eurasia and North Africa	4,120,000,000	24,200,000
(Eurasia)	(4,000,000,000)	(21,500,000)
(North Africa)	(120,000,000)	(2,700,000)
North America and South America	736,000,000	16,400,000
Sub-Saharan Africa	535,000,000	9,100,000
Australia	18,000,000	3,000,000